13 From Behaviorism to Constructivism

A Philosophical Journey from Drill and Practice to Situated Learning

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Both behaviorism and constructivism stem from centuries of philosophical musing concerning the nature of reality, our perceptions of reality, and even whether reality, as we perceive it, actually exists. The first and third of these issues are perhaps more than we might want to discuss here, but the second seems fair game. It allows us to progress from philosophy to experimental psychology and, finally, to what we might say about one aspect of constructivist thinking, namely, the situation of learning in authentic experiences. This chapter suggests that constructivist prescriptions for situated learning may be derived from our philosophical roots, empirical findings from experimental psychology, and experiences with situated-learning environments that rely on simulations. Much of the empirical support that is reported here derives from the use of simulation in military training, but let's start with some philosophers.

The Philosophers[1]

Like most concepts, including those in psychological science, constructivist ideas have a basis in philosophy. Earlier and other philosophical ruminations could be cited, but for this discussion we might well begin in the 17th century with John Locke's *Essay on Human Understanding*. Locke argued that everything in the mind was first in the senses, the mind being the now-famous *tabula rasa* for recording our perceptions. His notions led to the conclusion that observational evidence alone, received by the senses, produces knowledge of the world.

Reacting to Locke, the 18th-century philosopher, Bishop George Berkeley, issued his *Treatise Concerning the Principles of Human Knowledge*, asserting that nothing exists or has meaning unless it is perceived by some mind.[2] The cat sleeping under my dining-room table exists only because my senses have told my mind that he does.[3] Words and images are essential because they give both existence and meaning to matter. Berkeley went so far as to point out that the words we use for abstracting and labeling what our senses bring to our minds may evoke in other minds different meanings and, as we might say today, different associations. In his terms, the definition of reality is, for each of us, idiosyncratic.

So far, so good, but then David Hume came along to suggest in *A Treatise of Human Nature* that we know the mind itself exists in the same way we know the cat does—through our perceptions, although in the case of the mind the perceptions (e.g., ideas, memories, feelings) are internal rather than external. So we cannot be any more sure of what our internal senses are telling us about the existence of our minds than we can of what our external senses are telling us about the cat. At this point and as Durant (1933/1961) notes, "Hume had as effectively destroyed mind as Berkeley had destroyed matter" (p. 195). This is where Immanuel Kant comes in to rescue, perhaps, the cat and our minds.

Kant's *Critique of Pure Reason* asserted that not all knowledge is derived from the senses and he set out to prove it—at least as far as the notions of 18th-century philosophical proof allowed. He meant to establish the idea (and existence) of "pure reason" that allows us to discover a priori truths that are independent of all sense experience. Kant argued that pure reason is particularly impelled to find these truths. It is as if our reason is anxiously and irrepressibly searching for the reality, the general truths, that the fire reflects as shadows on the back of Plato's cave.

Durant noted that, "[Kant's] truths derive their necessary character from the inherent structure of our minds, from the natural and inevitable manner in which our minds must operate" (1933/1961, p. 202). Kant's idea of pure reason then seems reflected in Chomsky's (1965) notion of innate, deep-structure grammar, which he likened to the basic instruction set that comes with every computer. This notion draws an analogy between, on one hand, the effects of machine microcode on the higher-order functionalities of computers, and, on the other, the effects of very basic cognitive operations on the form and character of human thought, knowledge, and, in Chomsky's case, linguistic universals. If we had evolved from silicon instead of carbon, the pure reason underlying our mathematics, science, and language might be quite different than it is. One wonders how today's rapidly emerging findings on brain functioning would have affected Kant's reflections on the nature of pure reason.

The Psychologists

The intent of this discussion is not to burden the reader with philosophical ruminations but just to suggest that the roots of constructivism are long and honorable, that these ruminations transcend Locke's tabula rasa to posit active, constructive cognitive activity underlying all that we know, and that they lend depth and perspective to our constructivist notions today.[4] They anticipate William James' General Law of Perception, which he described as follows: "Whilst part of what we perceive comes through our senses from the object before us, another part (and it may be the larger part) always comes out of our mind" (1890/1950, p. 747).

Both Locke's positivist empiricism and James' constructivist views remain with us. Neither point of view is without controversy, but both appear to have a place in psychological theory and research, just as they do in the pragmatic business of applying psychological findings to the design and development of instruction.

Psychological researchers have long debated what the fundamental phenomena of their study should be. Those who prevailed roughly from the 1920s to the 1960s followed the early logical positivists and insisted that their research be limited to directly observable and measurable behavior. Consider the views of the quintessential 1930s behaviorist, John Watson. Never one to mince words, Watson asserted that: "consciousness is neither a definite nor a usable concept. The Behaviorist, who has been trained as an experimentalist, holds further, that belief in the existence of consciousness goes back to the ancient days of superstition and magic" (Watson, 1930, p. 2).

By way of contrast, consider the "central assertion" from Ulric Neisser's seminal 1967 text, *Cognitive Psychology*, that "seeing, hearing, and remembering are all acts of *construction*, which may make more or less use of stimulus information depending on circumstances" (p. 10; the italics are Neisser's). This quote raises a point worth emphasizing. Although the foundations of educational constructivism can be found in philosophy, they are also rooted in empirical data from reputable and extensive psychological research. Locke's own empiricism may lead us to reject his tabula rasa. One suspects he would have approved.

The basis for Neisser's assertion was a large body of research showing that the behavior we observe and measure under experimental conditions cannot be satisfactorily explained without postulating some features, characteristics, and activity for the mechanisms underlying it. For instance, he points to the considerable evidence that words in text can be recognized even when all the letters in the words are absent or illegible. He suggests that there must be some internal "analysis by synthesis" or a continuing "silent stream of thought" at work to account for this evidence (Neisser, 1967, p. 186). He makes a similar argument for phonemes, words, and sentences presented aurally. For these cases, he posits a relatively passive, pre-attentive perceptual mechanism supplemented by an active, internal, and ongoing synthesis that we use to make sense of the sparse perceptual cues being provided by our senses.

Neisser concluded that although the physical capabilities of our sensory receptors and the physical information they send to the brain can account for hearing and seeing, they cannot account for such cognitive processes as reading, speech perception, language understanding, analyses of complex visual scenes, or even the recognition of evocative aromas. Locke and the behaviorists can explain seeing, but we need Berkeley, Hume, and Kant along with constructivist psychology to understand perception. Sherlock Holmes understands this as he admonishes an earlier Dr. Watson, "You see, Watson, but you do not observe. The distinction is clear" (Doyle, 1892, p. 162). It appears that if we are to understand behavior, we must understand the constructive, internal workings of cognition.

Cognitive scientists have, then, come around to the view that human cognition, involving all perception, memory, and learning, is an overwhelmingly constructive process—that the world is to a significant extent, and as George Berkeley suggested, the creation of each observer who brings it about through a sensory simulation of his/her own devising. Even straightforward recall is not viewed as the retrieval of items whole cloth from memory, but as their reconstruction from more primitive cues—perhaps substantially aided and shaped by Kant's pure reason.

Neisser is not alone in this point of view. Psychological concepts ranging from Bartlett's (1932) schemata, Lashley's (1950) systems of associations, Tulving's subjective organization in free recall (1962), Craik and Lockhart's (1972) levels of processing, Baddeley and Hitch's (1974) multi-component model of working memory, and Mayer's (2005) model of multimedia learning can all be cited to support an empirically based, constructivist view of memory and cognition. Others could be added. On this basis and as some (e.g., Fletcher, 1982; von Glasersfeld, 1989, 1997) have suggested, we might, then, be advised to view perceivers and learners not as passive recorders of information transmitted to them over channels, but as active participants who use the fragmentary cues permitted them by their limited sensory receptors to construct, verify, and modify their own sensory simulations of the world.

Beyond issues of recall, constructivist views have persisted across many schools of thought in scientific psychology, suppressed as they were by Watson, Skinner, and others. These views can be found in the work of Gestalt psychologists such as Lewin (1951)—whose field theory and group dynamics described behavior in terms of the complex vectors we use to function in our environments—and even in the work of neo-behaviorists such as Tolman (1948)—who was willing to investigate internal phenomena such as goals, purpose, and cognitive maps. In short, a wide spectrum of psychologists saw a need to swing the research pendulum back from the strict logical positivism of behaviorism to consideration of internal, constructivist, cognitive processes.

Both sides of the behaviorist–constructivist issue have merit. Neither point of view is without controversy, but both appear to have a place in psychological theory and research, just as they do in the pragmatic business of instruction. In general, we do not want behavioral science to regress into an armchair study of gedanken phenomena independent of empirical verification. But, with a nod to Locke's empiricism, we would like to go where our data take us and better understand the empirical findings that emerge from experimental psychology, including, perhaps, today's neuro-physiological revelations about the organization of the brain and its functioning. And we would like to draw on them in designing and developing instruction.

Learning and Instruction

For some time and in a number of venues (cf. Duffy & Cunningham, 1996; Fletcher, 1982; Savery & Duffy, 1996; Tobias & Frase, 2000), we have been asking what the above findings of philosophers and experimental psychologists have to say for learning and instruction. The above discussion led us perilously close to the "Radical Constructivism" of Ernst von Glasersfeld, who also starts with George Berkeley but stirs in the philosophical considerations of Berkeley's contemporary, Giambattista Vico (e.g., von Glasersfeld, 1997). Though he follows different paths, von Glasersfeld ends up very close to the conclusions suggested here.

Dissatisfied with the "Radical Behaviorism" of Watson (quoted above) and in keeping with William James (quoted above), von Glasersfeld described Radical Constructivism as a form of pragmatism in which the uncertainty that our knowledge reflects an external, independent, objective reality leads necessarily to a concern with the world each of us constructs through our experience. He suggests that students "share with ... science, the goal of constructing a relatively stable and coherent model of their individual experiential worlds," and that without this fundamental assumption "we cannot lead them to expand their understanding" (von Glasersfeld, 1989, p. 13). So far, so good. However, he goes on to assert that "memorizing facts and training in rote procedures cannot achieve this" (von Glasersfeld, 1989, p. 13). This may swing the pendulum back too far. There may be good reason to consider the value of committing facts, basic concepts, and rote procedures to memory in learning and instruction. If we choose to be radically pragmatic, there may be much to say for drill and practice.

Drill and Practice

Drill and practice has become a popular target for derision among many designers and developers of instruction and especially those developing technology-based instruction. "Drill and kill" evokes images of bored students being driven relentlessly through linear sequences of meaningless instructional items. However, many early drill and practice programs worked very well and were enjoyed by their students (e.g., Fletcher & Atkinson, 1973; Fletcher & Suppes, 1975; Suppes & Morningstar, 1972; Vinsonhaler & Bass, 1972). These drill and practice programs adjusted content, sequence, difficulty, and pace for individual learners—capabilities occasionally listed today as defining characteristics of "intelligent tutoring systems." These programs were effective because they focused on explicit instructional objectives, data-based evidence of progress in achieving the objectives, promoting motivation and learner engagement through frequent interaction, and tailoring those interactions in real time to the needs of individuals.

Drill and practice programs appear to be particularly effective when their objectives require only a few cognitive steps to construct correct responses from stimuli or prompts.[5] For instance, associating the phoneme /at/ with the spelling pattern "at" in beginning reading or the word "gato" with "cat" in learning foreign-language vocabulary does not take many cognitive steps compared to problem solving or decision making. The same might apply to learning that "cat" is a mammal or the procedures to use in operating a can opener. Basically, this material involves simple, if not rote, remembering, understanding, and applying—to use terms adopted from Bloom's (1956) and Anderson and Krathwohl's (2001) hierarchies of learning.

Instructional content of this sort does not draw heavily on Hume's internal perceptions or Kant's pure reason. Learning in these cases resembles the business of plugging in items on Locke's tabula rasa. Drill and practice programs on arithmetic "facts" and spelling patterns and sight vocabulary in beginning reading that involve relatively straightforward associations between the stimulus presented and a correct response have in meta-analyses been quite successful, showing effect sizes of 0.50 and higher (e.g., Fletcher, 1997, 2003, 2004; Kulik, 1994). In these cases there is an unambiguous correct answer to each question, and the student's answer signifies fairly well if it has been learned or not. Students could eventually discover their way through properly constructed situated environments to learn material of this sort, but it seems far more efficient to deal with learning of this sort directly through drill and practice—students' time is after all worth something.

Logical positivism appears to work well in the design of these programs. One very precise measure of the Stanford mathematics program effectiveness was reported in "trajectory theory" evaluations developed by Suppes, Fletcher, and Zanotti (1975, 1976). Rather than employ the usual competitive race for achievement between control and experimental groups, trajectory theory attempted to account for student achievement strictly from the amount of time on task—the amount of time each student spent working with, in this case, computer-assisted instruction in arithmetic. Suppes et al. found that they could predict to the nearest one-tenth the comprehensive mathematics grade placement score on a standard test for 90% of the learners.

One aspect of instructional effectiveness keys on cost. Most administrative decisions about education concern not simply identifying and making improvements in instructional practice, but determining what must be given up in order to put them in place. Cost often turns out to be the most accessible measure of what must be given up, making the cost-effectiveness of instructional practices relative to others that are available a matter of central concern to decision makers.

The cost-effectiveness of computer-based drill and practice was examined by Fletcher, Hawley, and Piele (1990). Using experimental data reported by Jamison, Fletcher, Suppes, and Atkinson (1976), Levin, Glass, and Meister (1987), and a controlled study of their own, Fletcher et al. examined the costs (in constant dollars) to raise comprehensive mathematics scores on a standardized test one standard deviation using different instructional approaches: peer tutors, professional tutors, reduced class size, increased instructional time, and computer-assisted instruction. They found that the most cost-effective approaches among all these alternatives were computer-based instruction and peer tutoring and that, of the two, computer-based instruction was more cost-effective in three of four cases.

This result echoes the findings of Niemiec, Sikorski, and Walberg (1989) who compared studies of the costs and effectiveness of peer tutoring with studies of computer-based instruction. They found the two approaches to be equally effective and both to be more effective by about 0.4 standard deviations than conventional classroom instruction. Niemiec et al. also found a clear cost-effectiveness superiority (by a factor of about three) for computer-based instruction over peer tutoring—although as Fletcher et al. (1990) pointed out, the two are not incompatible and can be used together.

These positivist approaches take little note of learners' internal processing, but they, especially the effective ones, used various means to estimate the current state of the learners' progress toward achieving instructional objectives. For instance, consider a model, adapted from Paulson (1973), for use in tailoring instruction to individual learners. This model attempted to account for what happens when a student is asked a question concerning an item of knowledge—for example an arithmetic fact, an economic concept, or the next step in a standard procedure—and what happens when that item is not addressed but the student is asked to answer a question concerning some other item.

The model assumes that every item to be learned by a student is in one of three states in memory—learned, short-term, or unlearned. An item in the learned state for the student is assumed to stay in that state forever. When a question concerning an item in the unlearned state is presented, the item can advance to the learned state, the short-term state, or stay where it is. Similarly, when a question concerning an item in the short-term state is presented, the item can either advance to the learned state or stay where it is. When any item is presented to a student, other items in the short-term state for that student will either drop back to the unlearned state or stay where they are. All items for every student are assumed to begin in the unlearned state.

The model then attempts to account for transitions of items from one state to another by estimating the probability that they will occur. The model takes form in a transition matrix (Figure 13.1):

In words:

- If a learned item (state L) is presented, then:
  - with probability = *1*, it stays there.
- If an unlearned item (state U) is presented, then:
  - with probability = *a*, it will transition to the learned state;
  - with probability = *b*, it will transition to a short-term state from which it can either be learned or forgotten; and finally,
  - with probability = *1–a–b*, it will remain unlearned.
- If an item is in short-term state (S), then:
  - with probability = *c*, it will transition to the learned state; otherwise,
  - with probability = *1–c*, it will remain in the short-term state.

A key feature of this model is that it accounts for items that are *not* presented on a trial. In Paulson's (1973) formulation—based on Rumelhart's General Forgetting Theory (1967)—when an item is not presented but some other item is, transitions between states are expected to occur in accord with the transition matrix in Figure 13.2:

In words, when an item is not presented:

- if it is in the learned or unlearned state, it stays there with probability = *1*;
- If it is in the short-term state, it may regress to the unlearned state with probability *f* or remain in the short-term state with probability *1–f*.

Formulations such as this, which are based on explicit transition models of memory, tell us what state every problem or item is in for each learner. They focus on discrete items that are to be remembered, understood, or applied and stop there. They lead to very effective instructional strategies that are provably optimal in maximizing the number of items learned by an individual student in the total time allocated for instruction. Although these strategies account for the learner's state, they do not directly support the cognitive processes used by learners to develop, test, and revise their internal representations or models of the subject matter.

		State on trial n+1			
		L	S	U	P (correct)
State on trial n	L	1	0	0	1
	S	c	1–c	0	1
	U	a	b	1–a–b	g

Figure 13.1 Probability of an item's state transition when it is presented on trial n+1, given its state on trial n.

		State on trial n+1		
		L	S	U
State on trial n	L	1	0	0
	S	0	1–f	f
	U	0	0	1

Figure 13.2 Probability of an item's state transition when it is *not* presented on trial n+1, given its state on trial n.

Situated, Simulated Environments

At some point, then, learners may need to move up the knowledge hierarchy having first acquired a body of discrete items that can be learned—memorized, understood, and applied—through repetitive, behavioral, positivist approaches like drill and practice. These separate items of knowledge are often gleaned from a detailed analysis of the targeted subject matter and are intended to identify the elemental components it requires for competent performance. Once these items are learned and in order to advance their knowledge and competency, students must assemble, connect, and integrate these items into the analytic, evaluative, and even creative capabilities they need to solve problems, make decisions, and take effective action. In designing and developing learning environments to encourage this synthesis of discrete items into competent performance it seems reasonable, if not imperative, to support learners as much as possible in constructing, assessing, and modifying their internal, cognitive models and representations of the subject matter. One way to do this is to situate learners in "authentic" environments that they can use to develop, test, and hone these representations along with their subject-matter knowledge and skills.

Enter "learning by doing" and John Dewey. In Dewey's words, learning "is a continuous reconstruction, moving from the child's present experience out into that represented by the organized bodies of truth that we call studies" (1947, p. 11). Dewey focused on the learner's experience in such activities as planning, interpreting, problem solving, and decision making rather than the acquisition of discrete elements of "studies" such as facts and concepts. Most probably influenced by his study of philosophy, including his doctoral dissertation on Kant, Dewey emphasized the need for students to learn not just content but also processes of thinking—by becoming, in today's terms, "cognitive apprentices." This focus is echoed by Schuell's (1988) discussion of the learner's role in adding and constructing knowledge not explicitly provided by classroom teachers but that the learner needs in order to organize and make sense of the learning environment teachers provide. These and similar considerations lead us to constructivist, student-centered interests in situated-learning environments, which in turn lead us to the use of simulations in learning.

A claim of this chapter and its author is that constructivist theory in philosophy and experimental psychology leads directly to situated learning and that empirical support for constructivist notions in education may therefore be found in the considerable body of knowledge that has been collected, especially by the military, on the use and value of simulations in training. Before discussing instructional practice in this area we might caution against carrying it too far. Experience derived from situated, authentic environments is an essential element in learning and instruction, but research both early and recent suggests that unguided, free play does not yield the learning being sought (Clark, 2005; Gay, 1986; Kalyuga, Ayres, Chandler, & Sweller, 2003; Kirschner, Sweller, & Clark, 2006; Morrison & Meliza, 1999).

Enthusiasm for providing environments in which students reliably discover their way to the valid, internal representations required for human competence in any area must be tempered by the need for both guidance and explicit feedback. For example, Clark, in taking account of the need for guidance, developed Guided Experiential Learning (GEL) (2005). GEL is a pragmatic, systematically developed approach, based on research findings in information feedback, performance measurement, cognition and memory, and principles of instructional design, which integrates instructionally productive features of guidance and problem solving with situated, authentic environments.

In responding to the need for feedback, the US Army developed after-action reviews (AARs), which are based on similar research findings. Feedback provided by AARs after training exercises is not presented in a didactic manner, but as a facilitated discussion among the participants (Morrison & Meliza, 1999). All participants interact as equals discovering and diagnosing, with the help of exercise instrumentation, what happened during their engagements and how to develop what may be described as a shared mental model of the action. AARs have proven to be an invaluable source of feedback to participants in free-play training exercises that otherwise would remain shrouded in the fog of exigencies that these environments require for authenticity.

On the basis of these considerations, it may be past time to review some processes, analyses, and data extracted from the military's use of simulation-based training. Consider, for instance, the task of training pilots for combat operations. As discussed by Pohlman and Fletcher (1999), combat pilots must learn:

- *Basic Airmanship.* There are four basic dimensions to flight: Altitude (height above a point); Attitude (position in the air); Position (relative to a point in space); and Time (normally a function of airspeed). A pilot must control these four dimensions simultaneously. Doing so allows the aircraft to take off, remain in flight, travel from point A to point B, approach, and land.
- *Aircraft Systems Operation.* Combat pilots must also operate the aircraft systems. These systems include engine controls, navigation, fuel controls, communications, airframe controls, and environmental controls, among others. Some aircraft have on-board systems that can be run by other crew members, but the pilot remains responsible for them and must be aware of the status of each system at all times.
- *Navigation.* Once pilots master basic airmanship and aircraft system operations, they must learn to navigate in four dimensions. Pilots must maintain the aircraft in all types of airspace, in all manner of environmental conditions, at an assigned position, on an assigned course and heading. They must maintain altitude, or modify it at an assigned rate and airspeed while acknowledging and implementing constantly changing instructions.
- *Combat Weapons Systems.* Combat aircraft confront pilots with many additional systems to contend with. Combat pilots must understand how each weapon affects the aircraft when it is aboard and when it is launched. They must understand the launch parameters of the weapons, their flight characteristics, and the additional system controls they require. These controls consist of buttons, switches, rockers, and sliders located on the throttles and stick grip. The pilot must understand, monitor, and operate properly (while wearing flight gloves) all controls belonging to each system.
- *Survival.* All of the above must be attended to while people on the ground, at sea, and/or in the air are trying their best to remove our pilot from the scene—by any means available.

The task of flying fighter aircraft is one of the most complex cognitive tasks imaginable. A fighter pilot must be so versed in flying and operating the aircraft that nearly all of the tasks just described become automatic. Pilots describe this ability as "strapping the aircraft on." Although the temporal distance between stimulus and response must frequently and necessarily be very short for combat pilots, the number of cognitive processes between stimulus and response needed to identify, weigh, prioritize, evaluate, manage, and adjust issues of some urgency is very large. Refining these processes to the point of automaticity helps, but pilots must temper and balance these processes with cognitive judgments required to deal with specific circumstances, missions, and equally competent individuals who are trying to out-guess them.

The instruction we now provide to produce combat pilots uses a bottom-up process, providing drill and practice for the discrete knowledge and skills required. This process is complemented with top-down, simulation-based learning that situates the learner in approximations of the ultimate performance environment. Both instructional approaches are used to produce combat pilots and others who must perform similarly demanding activities. Locke still has his place, but so do Berkeley, Hume, and Kant.

Combat piloting may be an extreme example because of its time pressures, to say nothing of life-and-death issues, but the programs of instruction we provide seem applicable to many non-combat activities, such as emergency-room medical care, first responses to disasters, athletic competition, and so forth. Further, there are cases without similar time and/or survival pressures, such as business and operational planning, equipment troubleshooting and repair, and medical diagnosis, where cognitive steps between stimulus (internally and/or externally generated) and response are equally plentiful and complex and where the internal cognitive processes used to solve problems and make decisions must be optimized at least for correctness, if not, in these cases, for speed.

For all these cases, we may turn to learning environments supported by simulation, which can provide both full-task, highly realistic environments needed for situated practice and partial-task "coached" environments needed for more diagnostic, systematic instruction. Both environments can support development, testing, and modification of the representations that are needed for competent performance and both can compress the time needed to attain levels of expertise that would otherwise require a lifetime of job-site experience to acquire. Evidence of the impact of these simulation environments on development of internal cognitive models has been discussed by Andrews and Bell (2000)—among others—and can be found in research on shared mental models by Cannon-Bowers, Salas, Blickensderfer, and Bowers (1998) and Rouse, Cannon-Bowers, and Salas (1992)—among others.

The benefits of simulation include safety, economy, controlled visibility, and reproducibility (Andrews & Bell, 2000; O'Neil & Robertson, 1992; Orlansky et al., 1994; Raser, 1969). Simulated environments permit the attainment of training objectives that cannot or should not be attempted without simulation. Aircraft can be crashed, expensive equipment ruined, and lives hazarded in simulated environments in ways that otherwise range from the impractical to the unthinkable. Simulated environments can make the invisible visible, compress or expand time required in the real world for events to occur, and repeatedly reproduce events, situations, and decision points. They enable the attainment of instructional objectives that are otherwise inaccessible.

Simulation environments are intended to link instructional intervention directly to performance. In aircrew training the issue keys on transfer to see if the skills and knowledge acquired in simulation are of value in flying actual aircraft. Many attempts to answer this question rely on transfer-effectiveness ratios (TER) (e.g., Roscoe & Williges, 1980). These ratios may be defined for pilot training in the following way:

$$\text{TER} = \frac{\text{Ac} - \text{As}}{\text{S}}$$

Where:

TER= Transfer-Effectiveness Ratio;
Ac = Aircraft time required to reach criterion performance, without access to simulation;
As = Aircraft time required to reach criterion performance, with access to simulation;
S = Simulator time.

Roughly, this TER tells us how much aircraft time is saved for every unit of simulator time invested. Orlansky and String (1977) investigated this issue in an often-cited study. They found (or calculated, as needed) 34 TERs from assessments performed from 1967 to 1977 by military, commercial, and academic organizations. The TERs ranged from −0.4 to 1.9, with a median value of 0.45, suggesting that, overall, an hour in a simulator saves about 27 minutes (0.45 × 60 minutes) in an aircraft. Orlansky, Knapp, and String (1984) also compared the costs to fly actual aircraft with the cost to "fly" simulators. Very generally they found that the cost to operate a flight simulator is about one-tenth the cost to operate representative military aircraft. Assuming that an hour in a simulator saves about one half-hour in an aircraft, the use of flight simulators, overall, is cost-effective if the TER is 0.2 or greater.

At one level, this finding is useful and significant. However, a few caveats may be in order. First, Provenmire and Roscoe (1973) pointed out that not all simulator hours are equal—early hours in the simulator appear to save more aircraft time than later ones. This consideration leads to learning-curve differences between cumulative TERs and incremental TERs, with diminishing returns best captured by the latter.

Second, transfer is not a characteristic of the simulator alone. Estimates of transfer from a simulator or simulated environment must also consider what the training is trying to accomplish—the training objectives. This issue is well illustrated in a study by Holman (1979) who found 24 TERs for a CH-47 helicopter simulator ranging from 2.8 to 0.0, depending on which training objective was under consideration.

Third, there is an interaction between knowledge of the subject matter and the value of simulation alone. Clark and Estes (2002), Gay (1986), Tobias (1989, 2003), and others have emphasized that the less the student knows about the subject matter, the greater the need for tutorial guidance in simulation. Kalyuga et al. (2003) summarized a number of studies demonstrating an "expertise reversal effect" indicating that high levels of instructional support are needed for novice learners but have little effect on experts and may actually interfere with their learning.

Fourth, the operating costs of aircraft differ markedly and will create quite different trade-offs between the cost-effectiveness of training with simulators and without them. In contrast to the military aircraft considered by Orlansky et al.

(1984) where the cost ratio of aircraft to simulator was about 0.1, Provenmire and Roscoe (1973) considered flight simulation for the Piper Cherokee, where the cost ratio was 0.73.

Still, TERs are a significant capability for making instruction accountable in a quantitative fashion across many subject areas beyond pilot training. We have but to generalize their application by substituting actual equipment time (whatever that equipment may be) or real-world experience for aircraft time in the above TER definition and we are on the path to assessing the costs and effectiveness of situated instruction in achieving whatever competencies we wish the learner to achieve.

Given their probable utility, if and how TERs might be relevant to education deserves attention. Their utility may be found across many aspects of instruction—those involving the ability to solve ill-structured problems as well as those keyed to specific tasks and skills. Their use may reduce costs, increase safety, compress the experience needed to achieve both competence and mastery, and ensure that the instruction given is the instruction needed in a wide variety of applications. It suggests that TERs may deserve as much serious attention from educators as they have received from trainers—and from anyone concerned with informing decision makers about situating learning in relevant experience.

Does situated learning/instruction work? How well? These issues have been discussed at length in the area of military training by many commentators (e.g., Orlanksy et al., 1994; Gorman, 1990). A prime example of the approach is found in a natural experiment that occurred during the Vietnam War and led to the establishment of the US Navy's now famous Top Gun exercises, the US Army's National Training Center, and other combat training centers across the US military (Fletcher, 1999, in press).

In the air war over North Vietnam, the US Navy and US Air Force flew aircraft of comparable capabilities. In fact, many of the aircraft used were exactly the same, armed with the same weapons. During the first four years of air-to-air combat, both the Navy and the Air Force experienced an identical, and disappointingly low, loss-exchange ratio of North Vietnamese to US aircraft downed—2.2 to 2.4 North Vietnamese aircraft for every US aircraft.

There was a halt in air combat operations over North Vietnam from 1968 to 1970. During this period, the US Navy, but not the Air Force, initiated a training program using simulated, well-instrumented, force-on-force combat engagements to enhance pilot performance in air-to-air combat. The pilots flew aircraft, not simulators, so the flying was real, only the combat was simulated. Navy student pilots were pitted against "enemy" pilots—other, highly proficient Navy pilots trained in enemy tactics and flying MIG-type aircraft. Engagements were played and re-played until the Navy student flyers got them right.

In 1970 when the air war resumed, Navy pilots, still flying the same aircraft as their Air Force counterparts but trained using engagement simulation, performed about six times better than Air Force pilots whose training had remained unchanged. The new loss-exchange ratios were 2.0 for Air Force pilots and 12.5 for Navy pilots. No one calculated a TER for this experience, but the value of the simulated combat experience seems evident.

The success of situated learning in mock-combat environments gave birth to a host of combat training centers used to prepare military personnel for real-world operations (Chatham, in press; Fletcher, in press). These environments provide serious, situated practice with feedback. They are intended to provide training in emergent task environments involving tasks and activities that cannot be pre-specified in any deterministic fashion. The tasks evolve rapidly over time and in response to actions taken in the simulated environment. Communication and coordination between individuals, crews, teams, and units are free and uncontrolled. Outcomes are determined only by the participants' decisions and actions.

It is now commonly said (e.g., Gorman, 1990) that everything short of actual combat is simulation. In the First Gulf War, a cavalry troop commander led his nine tanks into a 23-minute attack that destroyed about 50 opposing tanks, 25 armored personnel carriers, 40 trucks, and a variety of other vehicles with no losses on his part. He was asked how he, who had no prior combat experience, had managed to accomplish this. He countered that was not the first time he had fought a battle. He had fought them in force-on-force engagements at the National Training Center (a mock-combat environment for land forces), in combined-arms live-fire exercises, and other simulations. He stated that he and his crews had simply carried out the correct drills automatically and completed them before realizing fully that they were not in a simulation (Fletcher, in press; McMaster, 1992, 2005).

Combat training centers may appear to be situated learning on steroids and a long way from the philosophical ruminations of Locke, Berkeley, Hume, and Kant on perception, reason, and reality; they may also seem remote from findings of psychological researchers on human cognition and learning, but the connections seem genuine. Designers and developers of these centers focus on the ability of participants to perceive the engagement through an internal cognitive representation they describe as "situation awareness" (e.g., Endsley, 1988). The centers themselves apply applications based on psychological principles of information feedback, performance measurement, cognition and memory, group processes, communication theory, sophisticated principles of instructional design, as well as much that the military has learned about situating training through the use of simulations.

Simulations have been used in much less dramatic training and education performed by the military. For instance, 24 studies of instruction using simulations based on videodiscs in residential military training for subject matter ranging from maintenance of electronic equipment to command and control to leadership found an overall effect size of 0.39 (Fletcher, 1997). Effect sizes for nine similar comparisons in industrial training averaged 0.51, and effect sizes for 14 comparisons in higher education averaged 0.69. Simulation based on videodiscs is, of course, passé today, but follow-on technologies using technology-based simulations in classroom use should show at least equal, if not superior, instructional effectiveness.

In considering learners as active constructors of cognitive models and mental simulations of the external environment, it should be emphasized that simulations and situated learning also help them test and verify these cognitive representations. Instruction using these approaches provides students opportunity to devise and test their own hypotheses concerning the subject matter by allowing them to manipulate and experiment with the simulations and view the results directly for themselves. It may take us back to Dewey's learning by doing, but it is common practice in today's military and elsewhere among today's game players.

Final Thoughts

Let's conclude with a few assertions that the preceding discussion was intended to support.

Constructivism has deep roots in philosophical thought. This foundation has led to a large body of findings in empirical, scientific research suggesting a need to posit internal, cognitive representations and "runnable models" (cognitive simulations) that we use to understand and deal with our environment. These representations are developed, tested, and modified based on the limited evidence provided by our senses. Effective instruction must, to some extent, create environments that support learners in this representation-building activity.

Most learning involves straightforward remembering, understanding, and applying, in fairly rote fashion, facts, concepts, and rudimentary procedures. This activity is most effectively and efficiently accomplished through repetitive, behavioral, positivist approaches such as well-designed drill and practice that promotes motivation and learner engagement through frequent interaction tailored to the individual learner's needs. These approaches should take account of the learner's state of knowledge with respect to the targeted instructional objectives, but it need not go farther to be effective in achieving these necessary, lower-order, objectives.

Much instruction is intended to go beyond these limited learning objectives and is intended to develop analytical, evaluative, and creative capabilities. Such instruction requires richer learning environments to support the learner's representation-building efforts. Prominent among these environments are those that situate the learner in "authentic" experience. These situated learning environments may be produced and provided through the use of simulations.

There exists much empirical evidence in training research literature concerning the design and effectiveness of simulation-based learning. This evidence may be used to support the tenets of constructivism in education.

Empirical evidence on effectiveness matters. It should support progress in developing our capabilities for producing environments in which people learn and decisions concerning our choices among alternative education and training interventions. It should provide systematically derived data on both effectiveness and costs. Perhaps in the spirit of Kant's concern with pure reason and/or Dewey's emphasis on the processes of learning rather than the content of knowledge, constructivists may resort to rhetoric and essays to support their instructional recommendations. It may be time to remember Locke's empirical positivism and attend more to providing data to support the representation-building efforts of skeptics.

Finally, it should be noted that in both philosophy and experimental psychology, behaviorism and constructivism may be driven to extremes. They should be viewed not as competing opposites but as complementary approaches in the pragmatic business of designing, developing, and delivering instruction.

Question: Kintsch. *Is decontextualized drill prior to authentic learning experiences the best way to go? Instead of forcing students to drill something they are not interested in (say, we make them memorize useful arithmetic facts until they thoroughly hate math), could we put them into the simulator first so that they discover what they need to learn? With a personal goal they care about, people are willing to put up with a lot of drill and practice—it is not just the soccer players who practice endlessly, but those few who develop more intellectual interests spend many hours of serious work in their pursuits, too.*

Reply: Fletcher. Merrill used to talk about "rule," "example," "practice" as, generally, the sequence best used in learning. We found through some experiments that "example," "rule," "practice" was more motivating and productive. This is to just to say righto—I agree with your notion of providing some simulator experience first as a way to motivate students to drudge their way through drill and practice on the facts, simple concepts, and straightforward, possibly rote, procedures they need in order to function successfully in whatever simulated or real environment you are preparing them for. It would also help learners solve the abductive problem of figuring out what, in a messy scene, is relevant and what is not. However, we probably don't want to throw students into simulated situations that are so difficult and bewildering that they are discouraged from the very start of instruction. And we probably wouldn't want to condemn students to an environment in which they are solely dependent on discovery to learn whatever they need to learn. For one thing it is inefficient—trainees' time is obviously valuable if we are paying for their training—but even in K-12 education, I claim students' time is, for many reasons, worth something. For another thing, discovery without support can actually be frustrating and de-motivating.

Drill and practice, if individualized and incentivized through competition, M&Ms, or whatever, can be quite motivating. Students in the Suppes and Atkinson K-12 drill and practice programs at Stanford could usually be coerced into good behavior by threatening banishment from the computer. All this is to suggest avoiding instruction that relies solely on simulation, discovery, guidance, or drill but rather seeking some balance among them. Okay, what's the balance? For what students, what instructional objectives, under what conditions? This looks like a job for research.

Question: Kintsch. *You make a good argument for drill and a good argument for simulators; can you elaborate on your claim that to have "acquired a body of discrete items ... through ... drill and practice" is a precondition for constructive learning, such as is involved in a simulator? What discrete items does a pilot have to be drilled in? How are they selected? How much drill? Is there evidence for the effectiveness of such drill in pilots undergoing simulator training?*

Reply: Fletcher. A glance, however cursory, into the cockpit of any airplane reveals the mess of instruments, gauges, dials, displays, and switches that pilots have to understand and apply. Those of us who fly frequently will be interested to know that the location and functionality of all this instrumentation differs markedly among different types of airplanes. This information needs to be well in hand, or in mind, in order to successfully fly an airplane or a simulator. I would cite the literature on individualized drill and practice as evidence for its use as an effective and efficient way for pilots to learn this material. There may be more effective and efficient environments in which to learn discrete matter of this sort, but none leap to mind. What does leap to mind are the problems, such as those discussed by Mayer (2004), that naive learners have with discovery learning. I would be tempted to cite these as evidence that a body of discrete items is a precondition for success in situated, simulator-based learning, and again I would be tempted to cite drill and practice as the most effective and efficient way to acquire them.

Also, there are things we would like pilots, surgeons, firefighters, cooks, and truck drivers to do automatically and correctly. People speak of just-in-time learning as a virtue, but there is much to say in favor of just-in-case learning. If a pilot notes from instruments that an engine is about to catch fire, we would not be encouraged if his first step is to turn to the index of an operator's manual to look up fire, engine, prevention. Again, I would point to drill and practice as the most effective, efficient way of achieving the necessary levels of automatic responding. I'd even go so far as to recommend over-learning through drill and practice as a way to ensure pilots and others will have retained these responses on those rare occasions when they are called for.

You asked, quite correctly, what sorts of things are appropriate for drill, how are they selected, and if drilled does that matter? Well, we might consider two dimensions: what is learned (facts, concepts, procedures, and metacognition) and the criterion for learning (remember, understand, apply, analyze, evaluate, and create). I claim that the closer we are to the fact-remember ends of the dimensions the closer we are to matters that are appropriate for drill. The closer we get to the metacognitive-create end of the dimensions, the closer we may be to items that are appropriate for situated, simulation-based approaches. So where, you might ask, is the point where we should shift from one approach to the other? Wish I knew. Your good question suggests the value of principles for determining the optimal quantitative balance between drill and simulation (for specific students, objectives, and conditions).

Question: Herman and Gomez. *We take your point that the pilot's simulator example is a good example of the blending of factual knowledge in the context of a highly situated practice that is significantly guided. The question for us is what is the relationship of knowledge that is required to be a pilot and the sorts of knowledge necessary for learning in traditional disciplines of schooling?*

Reply: Fletcher. That's a very good question for those of us who spend time bouncing between education and training and sitting on the cusp between. We might start with the notion that training is intended to prepare individuals and teams to perform specific tasks or jobs. In this sense training is strictly a means to an end. Success in terms of the knowledge and skills targeted is measured by success in doing the targeted tasks or job. Despite all the promotion of education as a key to expanded opportunities and income, I'd say that education is, in a very fundamental sense, an end in itself. It is preparation for life. And I'd say that the business of K-16 schools is primarily education and the preparation of people to fly aircraft is primarily training. However, there seem to be few training programs that do not contain elements of education and few education programs that do not prepare people to perform specific tasks. Also, they are both intended to produce learning. We teach penmanship, lab procedures, and arithmetic "facts" in education, and aerodynamics and Ohm's law in training. So I'd put education and training at opposite ends of a single dimension we might, for lack of anything better, call "instruction."

These considerations maybe point to John Dewey's concentration on process in education—generally learning to learn, problem solve, make decisions—rather than the specific things we are supposed to learn in training—specific problems we are supposed to solve or specific decisions we are supposed to make. So in training we might say that content is king and, in education, it's processes—perhaps the more abstract and "higher order" the better. However, I'd venture to say that the core differences between training to be a pilot and mastering the traditional disciplines of schooling do not key on the kinds of knowledge we present. Instead, I'd say, at least for the moment, that the primary difference lies in the intent or purpose of the instruction. We have to get electronic technicians to learn, understand, and apply Ohm's law so that they can repair radar repeaters, and we have to do the same to prepare students to be physicists. And I end up with the notion that situated (but guided!) simulation-based learning is as appropriate for educating K-12 students as it is for training fighter pilots.

Question: Herman and Gomez. *Some scholars argue that children and adolescents, unlike adult pilots, are not capable of carrying out the abstract cognitive transformations that are necessary for true knowledge construction. Presumably, such transformations are required to successfully use simulators for learning. Is this a valid concern when thinking of bringing simulator-like learning to the education of children and early adolescents?*

Reply: Fletcher. The glib response might be that if children and adolescents are incapable of the abstract cognitive transformations that are necessary for true knowledge construction how did they learn to talk? And maybe that's not so bad after all. As Chomsky pointed out ages ago (i.e., 1965), very young children learn (using Kant's pure reason?) to construct and utter sentences that they have never heard and have never themselves produced before. And they do so out of a resolutely situated, constructivist, discovery-learning environment. Could they do that without some capability for the abstract cognitive transformations needed for knowledge construction in simulation-based training? But that's not an entirely rhetorical question. Perhaps language learning is so different from all other kinds of learning that it simply doesn't apply to the use of simulators for learning. Perhaps the capability dies out at age six or so when language learning seems to require quite different cognitive pathways than it did for first-language learning.

That said, it seems likely that, through repetition and practice in a simulated environment, children might well be able to acquire the kinds of near-transfer, domain-specific skills required by a number of training settings. However, children do learn soccer, kite flying, violin playing, and quite complicated computer games. One might guess that they would be less capable of performing tasks requiring far and non-domain transfer. Someone once said that we constantly overestimate the language capabilities of children and underestimate their thinking abilities. A series of experiments with simulated environments involving different degrees of transfer might be called for here. No doubt you have noticed that I've answered your question by calling for more research. But I am tromping around in an area, developmental processes, that I rarely visit. I had better leave these issues to those who know what they are talking about.

Notes

1 Bibliographic note—in reviewing these arguments, I found Will Durant's *Story of Philosophy* (1961) to be most helpful. I quote from his book here and there and therefore feel obliged to cite my 1961 edition, which is out of print.
2 God's mind fortunately included, so that the physical world did not, for Berkeley, depend for its existence on human minds.
3 Let's set the cat's mind and perceptions aside for this discussion.
4 A more extensive discussion of the philosophical roots of constructivism, but following somewhat different paths, is provided by Duffy and Cunningham (1996).
5 The reader may discern an effort here to avoid debate over the distinguishing characteristics of declarative versus procedural knowledge.

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